

Effective Conveyor Belt Inspection for Improved Mining Productivity

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Abstract

This document details progress on the project “Effective Conveyor Belt Inspection for Improved Mining Productivity” during the period from May 15, 2006 to November 14, 2006. Progress during this period includes significant advances in development of a Smart Camera based prototype system for on-site mechanical splice detection, and continued deployment of both the mechanical splice detection system and the vulcanized splice detection system in area coal mines.

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1 Introduction

This report presents technical progress on the Effective Conveyor Belt Inspection for Improved Mining Productivity project, funded under U.S. Department of Energy award number DE-FC26-04NT42086.

The overall objective of the three-year project is to develop and commercialize a low cost conveyor belt inspection system for use in underground and surface mines, coal-fired power generation plants, and other large scale material handling operations. Mining operations rely on conveyor belts to move mined material from the working face to a processing plant. When a conveyor belt breaks or its operation is halted for unscheduled maintenance, there are often high costs in terms of lost productivity. For example, a mainline belt break in a longwall mining operation generally stops production for at least four hours. Concomitant revenue losses typically exceed \$240,000. CONSOL Energy has identified belt availability as one of the top two productivity bottlenecks in their operations today. Furthermore, belt repair under typical mine conditions is difficult, dangerous work. The system under development will help to reduce the negative impact of belt failure on production while improving worker safety.

During this 6-month period, we have focused our efforts on developing low-cost Smart Camera based conveyor belt inspection hardware which includes cameras, lighting, communications systems, and processing capability. The availability of a low-cost belt inspection system will allow mine operators to monitor all of the production belts in a mine, thus enabling its predictive maintenance capabilities to be applied broadly across a wide range of mine operators and conveyor belt types.

This project leverages a multi-year investment by CONSOL Energy for the National Robotics Engineering Consortium (NREC) at Carnegie Mellon University to successfully develop a belt inspection system for detecting mechanical splices.

The project continuation proposal describes the second-year objective as follows:

Budget Period 2 Objective

Complete tests and refinement of vulcanized splice algorithm on operating belts. Build, test, and demonstrate Smart Camera, which is the basic component of the low cost Belt Vision system for detecting mechanical splices. Install prototype on operating belt. Integrate vulcanized splice detection in working system and add full resolution recording capability to the Smart Camera. Determine if the engineering challenges associated with rip detection via structured light can be overcome. Continue test and development of RFID tags. Integrate into Smart Camera splice ID capability via RFID tags. Develop splice-numbering capability based on an input to camera that uniquely identifies a particular splice. Evaluate algorithms for detection of edge tears, which frequently are associated with failing vulcanized splices.

The following sections describe progress toward this objective.

2 Executive Summary

During this 6-month period, the vulcanized splice algorithm has been under continuous use in CONSOL mine installations. Meanwhile, development effort has been focused on designing and building

the low-cost Smart Camera. More detailed discussion of these accomplishments is presented in sections 3.1 and 5.

Vulcanized splice detection algorithm in daily use on operating belts The vulcanized splice detection algorithm remains in use at underground at both the Robinson Run and Blacksville mine sites.

Demonstration of low cost single-headed Smart Camera completed The laboratory prototype low-cost Smart Camera based belt inspection system has been significantly advanced, with final versions of the I/O board, CPU board and associated hardware, and Camera head being demonstrated in a benchtop environment.

16 developmental systems currently deployed A total of 16 pre-production (PC-based) low cost systems remain deployed underground in 7 different mines, including two at commercial customer sites.

Beitzel Corp is continues to produce and sell a very low volume of the pre-production low cost systems The logistics of deploying and supporting a system in mines dictate a cautious approach. Beitzel Corp is also continuing to survey belt managers for input into desired system features and potential new target markets.

More than 3 million cumulative miles of belt inspected by deployed evaluation systems In late 2006, the total inspected belt length passed the 3 million mile mark. In addition to providing unparalleled data on the appearance and evolution of splice images, these installed systems provide important experience with system reliability and usability, as well as having a daily positive benefit on operations in the host mines.

3 Experimental

3.1 Smart Camera Development

The current BeltVision prototypes are built using off-the-shelf cameras, frame-grabber cards, and computers. This approach allowed the system to be developed quickly, and the current design is in daily use at 7 different mines, however it has several drawbacks:

Expense: The frame grabber cards and cameras are expensive, adding thousands of dollars to the price of the system.

Reliability: Packaging a commercial PC for use in a commercial mine is quite difficult. The environment in the mine is harsh, dirty, and dangerous. The computers are installed in totally enclosed cabinets, which makes it a challenge to cool them properly. These factors combine to significantly increase the maintenance requirements of the system.

Size and weight: The installation sites for the BeltVision units are often far underground, and access often requires travel by foot for some portion of the journey. In the current system the

enclosure for the PC is large and heavy. This adds significantly to the difficulty of both routine and unscheduled maintenance

In order to address these concerns, a low-cost Smart Camera based version of the BeltVision system is under development. The initial design includes a Perkin-Elmer line scan sensor element, image capture hardware, a Xilinx FPGA to implement the computer vision algorithms, and a Motorola ColdFire CPU to handle ethernet communication and control the operation of the system. The result of this effort will be a system in which all of the the sensing, processing, and communications are carried out by inexpensive units which are smaller than a loaf of bread, and weigh under 5 pounds. With these small, light, inexpensive units, system maintenance will consist of simply unplugging any malfunctioning units and replacing them with parts from a backpack or box.

At the time of the previous semi-annual report, a very early laboratory prototype of the Smart Camera had been completed at Imaging Systems Group (ISG) in Hauppauge NY, and had passed preliminary tests at Beitzel Corporation. In the past 6 months significant progress has been made toward completion of a fully functional Smart Camera. Much of this work has been performed at ISG. This progress is described below.

3.1.1 CPU Board and I/O Board Design

Printed circuit boards for the camera subsystem, computing boards, and I/O hardware were designed, assembled, and tested. The final designs represent a significant step forward from the early prototype demonstrated in the previous 6-month period, including a much more powerful FPGA, additional I/O hardware, and upgraded display capability. These changes allow several important additions to the functionality of the system:

- Improved handling and buffering of image data, including JPEG compression and decompression on-the-fly.
- Provision for local control via LCD display and keypad.
- Ability to simultaneously interface with two line-scan sensing heads. This allows the entire width of the conveyor belt to be imaged at once.
- Image alignment routines so that data from the two sensing heads can be easily integrated.
- Improved communication with supervisory PCs via ethernet to allow numbering of splice images, control of detection parameters, etc.

3.1.2 Mechanical Design and Fabrication of System Enclosures

Housings for the computing and camera-head assemblies were designed, and camera-head enclosures were fabricated. Figure 1 shows a camera head with sensing element and I/O board installed. These camera heads will replace the expensive commercial line-scan cameras in the current BeltVision prototype, and connect to the CPU housing using an inexpensive HDMI cable.

3.1.3 Assembly and Testing of System Components

The designs of section 3.1.1 were fabricated and tested for proper function. A photo of a fully assembled and functional processor board is shown in figure 2.



Figure 1: A partially assembled camera head for the Smart Camera based BeltVision system.

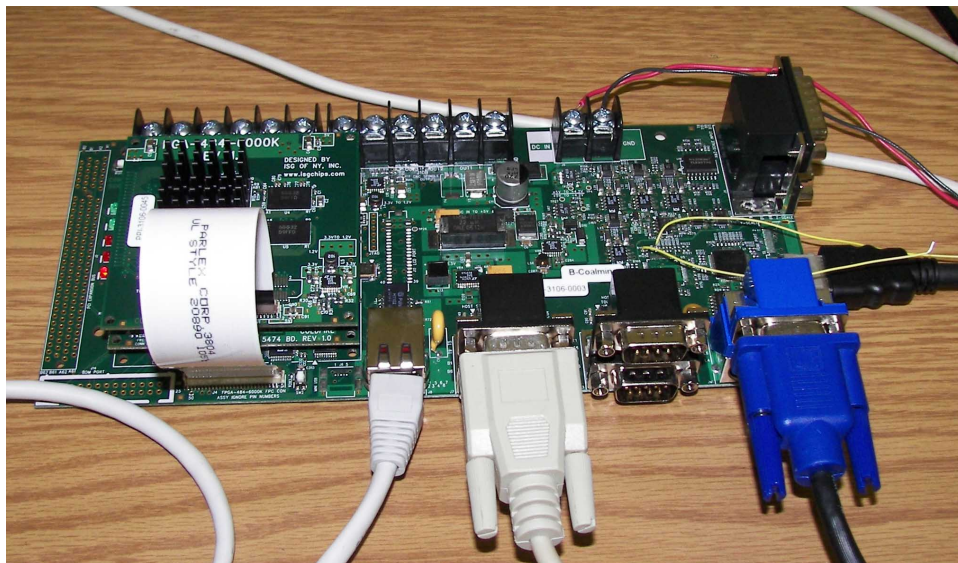


Figure 2: A fully functional computing board for the Smart Camera, photographed during demonstration at ISG in September, 2006.

3.1.4 Image Path Architecture

The image data pathway from the sensors, through the FPGAs to video memory was finalized and implemented. Image data is JPEG compressed early in this pathway to reduce video memory requirements. In addition to processing the image data to detect splices, the final architecture supports export of images over ethernet, image decompression for display on a local monitor, and automatic annotation of displayed images to reflect splice number, date of detection, etc.

3.1.5 Local Software Development

The FPGA code originally developed for the 400,000 gate FPGA in the demo system was ported to run on a larger, more powerful FPGA, and additional code was written to support more flexible image output, reporting of splice detection results, and buffering of image data.

Still more FPGA software was developed to perform JPEG compression and decompression of the image data. Compression is required in order to reduce video memory requirements. Decompression is required for the local display, and must occur concurrently with the JPEG compression. Code was also developed to allow horizontal and vertical offset image adjustments so as to match up the scan lines from two individual camera heads as if they came from one camera head with an extra-wide field of view.

Software was developed to allow interfacing with the Smart Camera over ethernet, and code was written to implement the image annotation and display features called for in the image path design. This code includes software to manage a local LCD display and keypad.

4 Results and Discussion

When deployed, the Smart Camera based BeltVision system will include two camera heads connected to a single FPGA/CPU housing. Pending integration of the second camera head, a single-headed system was bench tested in September, 2006. Camera input was simulated by moving pictures of mechanical splices past the sensor head, and splice detector functionality was monitored via PC, as shown in figure 3. Internal software diagnostics indicated correct functioning of the splice detection algorithm, and qualitative performance was deemed acceptable. Integration of the second sensor head is expected to be complete in early 2007, and a more rigorous belt-mounted test is being scheduled.

5 Additional Progress

Additional efforts at CONSOL and Beitzel Corp. have focused on two areas: optimizing lighting conditions so that vulcanized splices are more easily detected, and continued refinement of an RFID tag reading system for on-the-fly identification and measurement of vulcanized splices. Studies were conducted to assess how accurately the RFID tags can be used to measure belt stretch, which may be predictive of impending splice failure.



Figure 3: A bench test of a single-headed Smart Camera system was conducted at ISG facilities in Hauppauge, NY.

6 Conclusion

During this 6-month period, we have focused on development of a Smart Camera based BeltVision system, with some additional effort directed to refining the vulcanized splice detection algorithm and further testing of RFID-based belt monitoring.